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ENERGY PRODUCTION AND CONSUMPTION CHARTS IN ENERGY SYSTEM

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The main task of the energy system is to supply the consumers with high-quality electric and heat energy. As possibilities for accumulation of the energy and especially electrical energy in Estonia are very limited, one of the main energy parameters is its uninterrupted supply. The needs of consumers are characterized by the demand curve – the variation of load for a given time period (day, month, year). It is necessary to stress the difference between load and demand curves for the producer and consumer. Up to the recent time the producer load curve consisted of the individual consumers' demand curves sum plus losses in the distribution elements (in electric networks). Nowadays when by economical and ecological reasons the renewable energy sources are more intensively used, the part of the energy producers using wind and solar energy is constantly rising, and they are increasingly influencing the work of the whole energy system. That complicates significantly the work of the high-powered electric energy generators (with large inertia) at power stations as, in addition to the load variations depending on demand, they have to compensate extremely stochastic production of wind turbines. In this paper the problem is discussed on the basis of load and demand curves of the Energy system of Estonia and Pakri wind farm. It is shown that these curves are not suitable for mutual compensation and that may disturb the stability of the energy system at the wind park maximum power. The result is that the Energy system dispatcher is forced to limit the production of the wind park.

Introduction

Practically almost all the electric energy consumed in Estonia and noticeable part of heat energy are produced by electric and cogeneration power stations belonging to the uniform energy system and transported to the consumers by the district-heating and electric networks. As for electric energy, since there is a uniform electrical system for the whole country, district-heating net-

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works are due to technical reasons limited in length, and mostly the district-heating plants of smaller capacity (town, village or part of it) produce the heat energy. Centrally produced electric and heat energy is carefully measured and accounted for, and there is statewide statistics concerning the amount of energy produced and consumed [1]. Besides that, there are also a large number of small-scale individual producers of heat energy for their own needs whose consumption rates may be estimated very roughly. In 2007 in Estonia 12 139 GWh of electric energy were produced from which 12 024.4 GWh or 99.06 % by thermal power stations using mineral fuels, 18.9 GWh (0.15 %) by hydroelectric power stations and 95.7 GWh (0.79 %) by wind turbines [1]. The amount of the heat energy produced at electric power stations and district-heating plants in the same year was altogether 8 522 GWh. The distribution of different fuels used for the electric and heat energy production is given in Table 1.

The amount of electric energy produced in 2006 from wind and hydro-energy was 88.3 GWh that forms 0.91% of the entire electric energy production. The amount of electric energy produced from mineral fuels in 2006 W_e was therefore 9 610.7 GWh (99.09%). The energy content of these fuels W_k was 88 915 TJ (24 718.37 GWh). We can see that the electrical efficiency of thermal power stations in Estonia was:

$$\eta_e = (W_e / W_k) \cdot 100, \qquad (1)$$

that means 38.9%.

Table 1. **The fuels used for centralized production of the electric and heat energy in Estonia in 2006**

Fuel	Electric energy		Heat energy		Electric and heat energy altogether	
	TJ	%	TJ	%	TJ	%
Coke	0	0	271	0.63	271	0.20
Oil shale	83 393	93.75	5 980	13.79	89 373	67.57
Milled peat	102	0.11	968	2.23	1 070	0.81
Lumped peat	0	0	563	1.3	563	0.42
Peat briquettes	0	0	15	0.03	15	0.01
Firewood	0	0	519	1.2	519	0.39
Woodchips and wood waste	3	0	6 893	15.9	6 896	5.21
Wood briquettes and pellets	0	0	39	0.09	39	0.03
Natural gas	2 341	2.68	19 371	44.67	21 712	16.41
Liquid gas	0	0	5	0.01	5	0.00
Heavy fuel oil	1	0	224	0.52	225	0.17
Oil shale fuel oil	302	0.34	3 477	8.02	3 779	2.86
Light fuel oil	0	0	1 245	2.87	1 245	0.94
Diesel fuel	10	0.01	22	0.05	32	0.02
Other fuels (oil shale and biogas)	2 763	3.11	3 766	8.69	6 529	4.94
Altogether	88 915	100 0	43 358	100	132 273	100

Table 2. **Electric and heat energy production by thermal power stations, district-heating plants, and wind and hydroelectric power stations per month in 2006 (GWh)**

Month	Electric energy				Heat energy from thermal power and district heating plants
	Power stations	Wind plants	Hydro plants	Total	
January	1 018	7.7	1.2	1026.9	1 305
February	949	3.4	0.6	953	1 258
March	951	5.7	0.7	957.4	1 220
April	652	5.7	2.9	660.6	788
May	724	4.9	1.9	730.8	439
June	626	3.7	0.9	630.6	340
July	644	3.6	0.3	647.9	278
August	876	4.3	0.2	880.5	314
September	636	5.7	0.2	641.9	345
October	888	7.8	0.4	896.2	631
November	864	8.7	1.5	874.2	926
December	871	13.3	2.1	886.4	941
Altogether	9 699	74.5	13.8	9787.3	8 785

The percentage of the renewable fuels in electric energy production was comparatively small, and it is not possible to define it exactly as there is no data on the amount of biogas used. In production of heat energy, the part of biofuels is larger as at district-heating plants the firewood, wood chips and wood wastes, wood briquettes and pellets form nearly 6% of the whole amount of fuels used, and at individual furnaces, the biofuels are the main energy source. At thermal power stations and district-heating plants W_k = 43 358 TJ (12 043 GWh) of fuel energy was used to produce W_s = 8 785 GWh of heat energy, and the efficiency of heat production was:

$$\eta_s = (W_s / W_k) \cdot 100 = 72.9\ \%. \tag{2}$$

The part of oil shale in electric energy production at thermal power stations was 93.75% and in the centralized production of heat energy 13.79%. In the next 15–20 years there evidently will be no significant reduction of the oil shale role in Estonia [2]. Statewide statistical institutions have only the most general data – the monthly production and consumption. More exact shorter periods data is available from the organisations producing, distributing or consuming energy.

Production and consumption charts

As we try to show in this paper, it is useful to make difference between the producer and consumer load and demand curves presented in the form of charts. The demand curve by common terminology is a graphically described change in electric, heat or some other load during some period [3]. The length of the period is usually one year, month or day, and the demand curve characterizes consumption of electric or heat energy by individual consumer, group of consumers, of settlement or some other administrative unit (the whole country as well), and so, the load curve is dictated by the needs of consumers.

The use of the load curve term is caused by the widening electric energy production based on natural phenomena not influenced directly by people (wind, sun and to a certain extent the water at small hydroelectric stations). The owners of such energy production systems, declaring that their energy is cost-free (when such system is already installed), try to "cram" their electric energy into the public electric network independently of the needs of consumers (their demand curves), making the load curves of electric power stations and network more choppy. That leads to greater losses in the network and to smaller efficiency of the system [4], and if the production peaks of such energy producers exceed a certain level, the stability of the electric energy system as a whole may become endangered.

The load or demand curve of the year shows usually monthly production of electric or heat energy or consumption depending in the first place on weather conditions. Figure 1 shows the centralized electric and heat energy production (at electric energy thermal power stations and district-heating plants) data for 2006 in Estonia.

From the chart, we see sharply expressed lessening of demand in summer months, especially in the heat energy part. It diminishes significantly the possibilities of using renewable energy (wind) for heat energy production in summer months, because the large part of heat energy as by-product of electric energy production is not used at that time. Saving of heat energy for longer periods is limited, and the efficiency of it is comparatively low.

For comparison, the monthly production of electric energy in 2006 by the wind and hydroelectric power stations in Estonia is given in Fig. 2.

We can see that monthly production of the wind energy is in quite good correlation with heat and electric energy demand. It means that at least a part of the (heat) energy may be produced by wind. However, as the wind at the

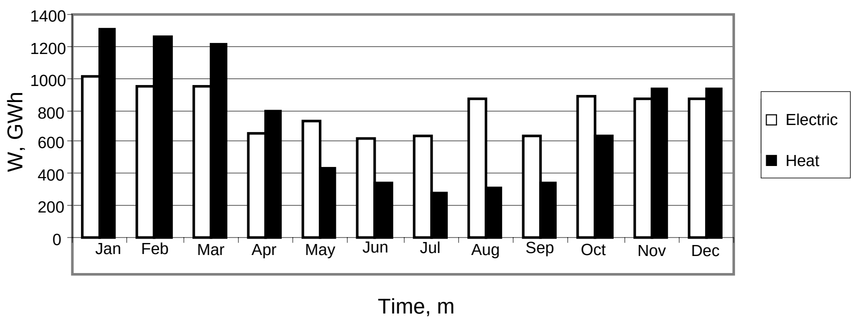

Fig. 1. Centralized production of electric and heat energy in Estonia (2006).

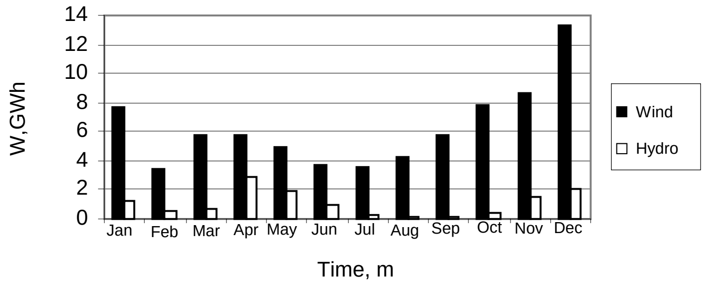

Fig. 2. Load curves of wind and hydroelectric power stations in Estonia (2006).

given place may change significantly by the hour or minutes (even seconds often), production curves of the shorter period are needed for the analysis of the energy production dependence on the wind parameters' variation. The complex analysis of these curves should be made for a longer period.

The influence of hydroelectric power stations on the energy production in Estonia is very moderate. By their load curve, it is possible very clearly to define the periods of the snow melting in spring and rains in autumn (Fig. 2). The more specific analysis of the hydroelectric stations and their development in the future is presented in literature [6]. Though the financing of the new projects is going on, there are many obstacles thanks to the environmental requirements becoming stricter.

As an example of wind energy production, we suggest the load curve of July 2006 (Fig. 3). It is interesting because we can clearly see the cutting off the disturbing excess power peaks in the middle of the month by the control staff of the power supply system.

In the analysis of the wind turbines work it is practical to use the concept of maximum (or nominal) power utilization factor that may be described as

$$k_m = \frac{W_{tn}}{P_m \cdot t_n} \cdot 100, \qquad (3)$$

where W_{tn} is energy produced by the wind turbine (turbines) in time period t_n, P_m – maximum power (sum of the nominal power of the of the wind

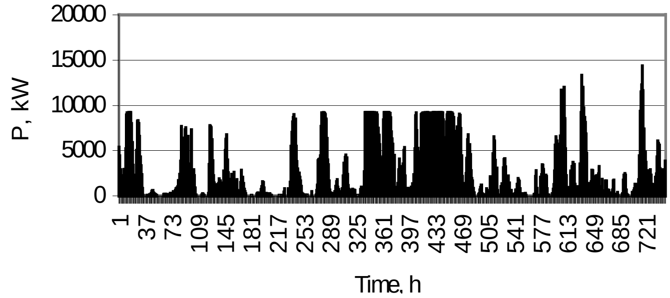

Fig. 3. Power load curve of Pakri wind farm (July, 2006).

turbines). Here $P_m\ t_n$ is the energy amount that would have been produced by all the generators working at nominal power for time t_n.

According to the load curve in Fig. 3, the output power of Pakri wind farm was periodically limited by the Energy system dispatcher, and the corresponding power utilization factor was comparatevely low – 15.6%.

For calculation, we need an equation of the power curve that may be found using the wind turbine data [5]:

$$P_n = 0.0011v_n^6 + 0.0808v_n^5 - 2.1742v_n^4 + 24.297v_n^3$$
$$-88.608v_n^2 + 90.616v_n - 0.8286\,. \quad (4)$$

At the wind speed $v < 4$ m/s the turbine output power is 0, but the equation gives us negative results, so it may be used with an additional condition:

$$if\ v_n < 4,\ \ P_n = 0. \quad (5)$$

The energy amount produced is:

$$W = \sum(P_n \cdot \Delta t_n)\,, \quad (6)$$

where P_n is average power in Δt_n period.

The load curve of the wind farm calculated using the wind speed is shown in Fig. 4.

The maximum power utilization factor for this curve is approximately 20%, nearly 4% higher than for the real curve.

The daily electric energy production of Pakri wind farm for July 2006 is shown in Fig. 5, and it is much less informative as there is no periods with zero production visible as in Fig. 3.

The impact of the wind farms' load on the work of the energy system is most evident from the hourly curves as just the sharp production variations are too short for large energy blocks of the power stations to follow up and

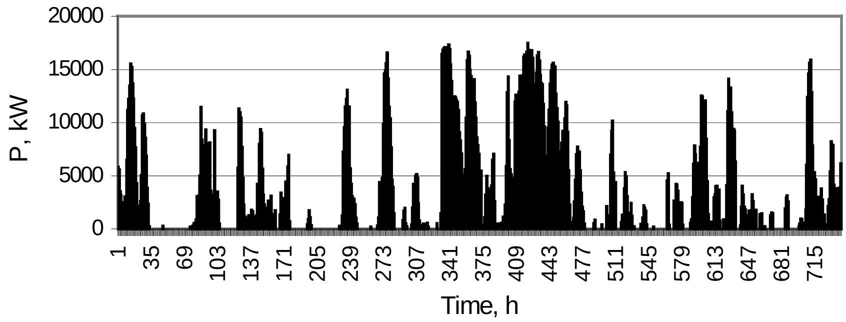

Fig. 4. The possible power load curve of Pakri wind farm (July, 2006).

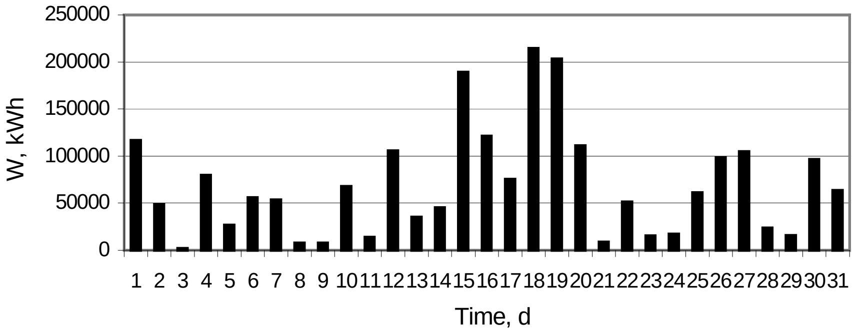

Fig. 5. The daily electric energy production of Pakri wind farm (July, 2006).

to lessen their fuel consumption according to the smaller demand, and their effectiveness diminishes considerably.

As an example, we shall take two days – with minimum and with maximum electric energy production. In Fig. 6 we see the hourly electric energy production by Pakri wind farm in July 3, 2006 when the load was minimal.

The twenty-four hour calculated energy production on July 3 was 2 095 kWh, and corresponding maximum power utilization factor was 0.47%. The hour average power was 87.3 kW, taking into account also an 8-hour gap with nearly zero production.

For comparison, Fig. 7 shows the load curve of the Estonian Energy system for the same day.

It is evident that such choppy load curve (Fig. 6) of the wind farm is unsuitable from the point of view of the energy system, as the work conditions for the main power-generating stations are most favourable in the case of a level load curve.

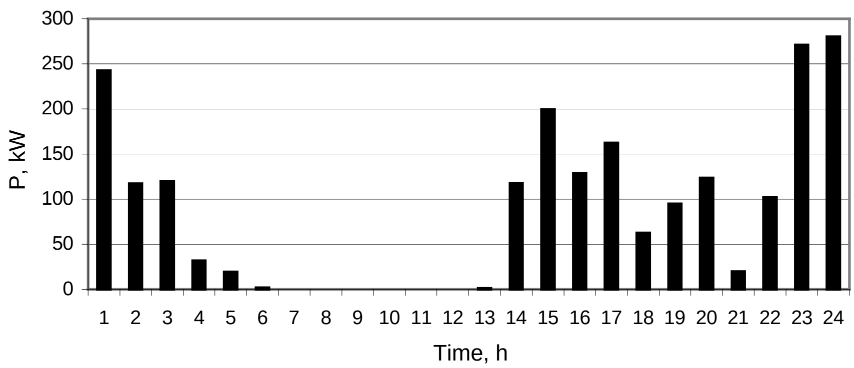

Fig. 6. The hourly electric energy production of Pakri wind farm (July 3, 2006).

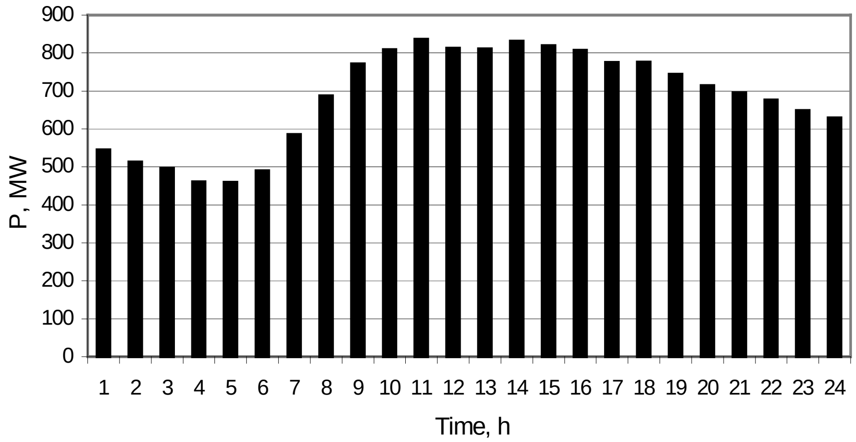

Fig. 7. The load curve of the Estonian energy system (July 3, 2006).

The energy production of the wind farm on July 18 (Fig. 8) was cut off by the energy system dispatcher approximately to 50% of the maximum power with resulting energy production 214 560 kWh and maximum power utilization factor 48.59%. The theoretical load curve of the same day defined by Eq. 4 on the basis of the wind speed data is shown in Fig. 9.

The energy production of the day would have been 339 293 kWh and maximum power utilization factor 76.8%.

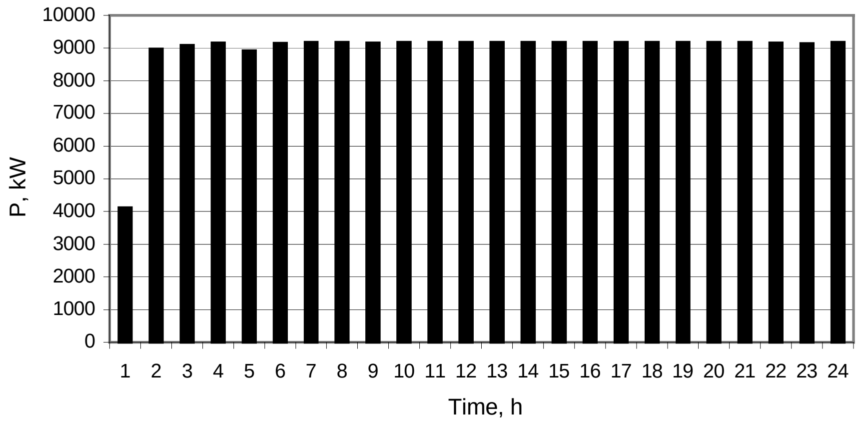

Fig. 8. The hourly electric energy production of Pakri wind farm (July 18, 2006).

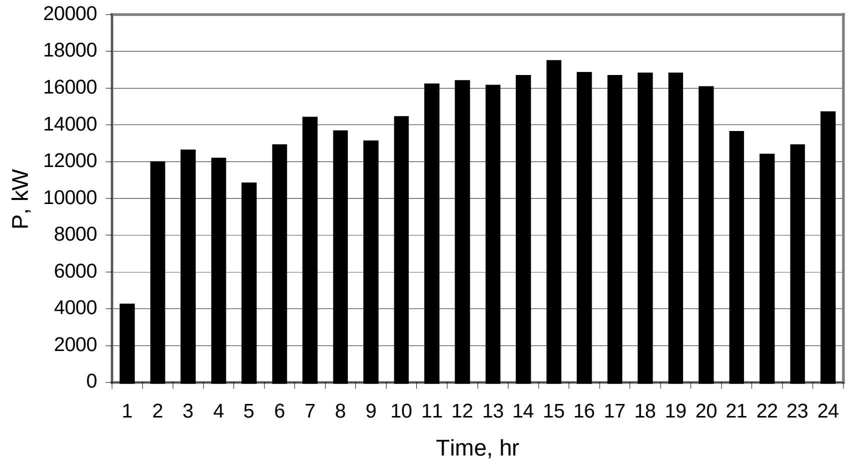

Fig. 9. The hourly theoretical, based on the wind speed, electric energy production of Pakri wind farm (July 18, 2006).

Summary

The unfitness of energy production curves of wind farms for load curves of the Energy system and extremely stochastic character of the power output of wind farms will result in serious problems for the Estonian Energy system with the increase of wind energy production. More specifically these problems are described by Tallinn Technical University researchers [7–9].

The conclusions of this analysis are:

1. The comparison of the load curves of the wind farms and curves of electric and heat energy demand shows some correlation between them that allows to use at least some of the wind energy for heat energy production in case of sufficient accumulation possibilities.
2. At the same time the comparison of shorter period (daily) curves shows that it is difficult to fit the wind farm load with electric energy demand, and that the wind energy supply to the energy system does not lessen proportionally fuel consumption and environment pollution by power stations.
3. Equation 4 suggested by the authors makes it possible to calculate the output power of the specific wind turbine according to wind conditions.
4. One of the most real possibilities to improve the utilization of wind power from the energy system point of view is introduction of the **real time tariff** [10, 11] when the „excessive" wind energy utilization becomes the consumer problem.

REFERENCES

1. Statistical database: Economy − Energy − Energy consumption and production. http://pub.stat.ee/px-web.2001/I_Databas/Economy/07Energy/02Energy_ consumption_and_production/01Annual_statistics/01Annual_statistics.asp [24.01.2009].
2. *Tammeoja, T., Reinsalu, E.* Forecast of Estonian oil shale usage for power generation // Oil Shale. 2008. Vol. 25, No. 2S. P. 115–124.
3. Estonian Encyclopaedia. Vol. 5. Tallinn, Estonia: Valgus, 1990. P. 740 [in Estonian].
4. *Kokin, E., Peets, T., Jürjenson, K., Lepa, J.* The shape factor of demand curve // Agricultural Machinery, Buildings and Energy. Transactions No. 204. Tartu: Estonian Agricultural University, 1999. P. 90–94 [in Estonian].
5. Nordex_N80- N90 Product Sheet. http://www.nordex-online.com/fileadmin-/MEDIA/Produktinfos/EN/Nordex_N80-N90_GB.pdf [24.01.2009].
6. *Raesaar, P.* Resource and utilization of Estonian hydropower // Oil Shale. 2005. Vol. 22, No. 2S. P. 233–241.
7. *Liik, O., Oidram, R., Keel, M., Ojangu, J., Landsberg, M., Dorovatovski, N.* Co-operation of Estonia´s oil shale based power system with wind turbines // Oil Shale. 2005. Vol. 22, No. 2S. P. 127–142.
8. *Meldorf, M., Täht, T., Kilter, J.* Stochasticity of the electrical network load // Oil Shale. 2007. Vol. 24, No. 2S. P. 225–236.
9. *Valdma, M., Keel, M., Tammoja, H., Kilk, K.* Reliability of electrical power generation in power systems with thermal and wind power plants // Oil Shale. 2007. Vol. 24, No. 2S. P. 197–208.
10. *Lehtla, T., Järvik, J.* Estonian possiblity – real time electricity tariff // Eesti Päevaleht. 24.03.2008 [in Estonian].
11. *Tänavsuu, T.* Smart meter is gaining share // Eesti Ekspress. 20.03 2008 [in Estonian].

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